

MT. TRUMBULL EXPERIMENTAL RESTORATION BLOCKS

MT. TRUMBULL RESTORATION PROJECT PROGRESS REPORT

APRIL 1999

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INTRODUCTION

This document is a mid-year progress report on the status of experimental research on the Mt. Trumbull, AZ ecosystem restoration project, and focuses on data collected and analyzed from the Mt. Trumbull experimental restoration blocks. This report is prepared by the Northern Arizona University research team, headed by Dr. Wally Covington.

To fully understand the effects of restoration on ecosystem structure and function, confounding variables, such as weather, site differences and grazing schedules, must be accounted for. These variables can be reduced or removed by designing paired treatment and control experiments, where the effects of a treatment can be tested alongside the effects of no treatment. In a paired block design, differences between control and treatment units are due primarily to the treatment, as all other variables have been held constant, or removed. A series of five experimental blocks (EB), each containing a control and ecosystem restoration treatment, were established at the Mt. Trumbull ecosystem restoration project. The purpose of the experimental blocks is to quantify restoration effects through intensive measurements at these five controlled study sites.

Each block consists of a nominal 40-acre area divided into two similar units. Treatments, ecosystem restoration and control, were randomly assigned to each unit, with the corresponding treatment and control units in each ranging from 20 acres to 50 acres. At this scale, variables including invertebrates, small mammals, birds and soil structure can be examined in addition to the vegetation and fuels monitoring. These taxa contribute greatly to ecosystem function and are important to monitor in landscape level experiments. This experimental design has attracted many researchers from NAU to initiate projects in these blocks.

Specific research questions addressed in the experimental blocks include, but are not limited to: How does the overstory and herbaceous community respond to restoration treatment? How are fuels affected by the restoration treatment? How does fire behavior change in a restored ecosystem? What effect does the edge created by restoration treatment have on abiotic variables, butterflies and bird communities? How does the small mammal community respond to restoration? How does the herpetological community respond to restoration? Does restoration increase butterfly community diversity and abundance?

A large-scale experimental design such as this is difficult to establish and experimentally treat. The Arizona Strip District of the Bureau of Land Management has provided the site and operational support to accomplish the treatments in this experiment. The researchers would like to thank the Strip District for their patience and perseverance to treat all experimental blocks within a year.

This report presents the pre-treatment vegetation survey data collected from 1997 – 1998. A list of the plants found in the survey area is provided in Appendix A.

METHODS

STUDY SITE SELECTION

Five experimental blocks were placed in the Mt. Trumbull Resource Conservation Area (RCA). The sites were chosen to block for landscape heterogeneity and were located in areas representing the different vegetation, topography and land-use history.

Mount Trumbull RCA

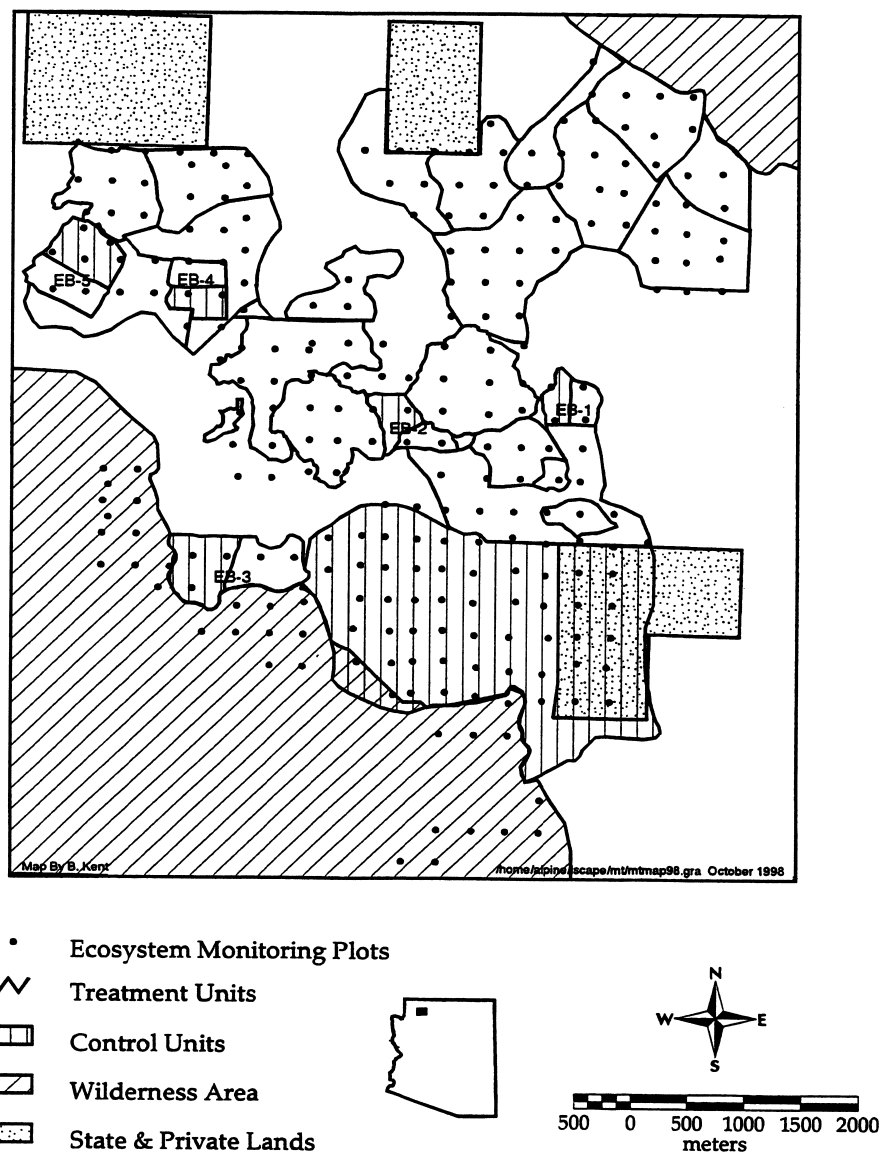


Figure 1. The location of experimental blocks 1 - 5

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The five experimental blocks vary in soil type, forest density, forest composition and herbaceous cover. Listed below is a brief description of each block:

Block 1: Located on shallow lava/cinder soils, this block has low tree density, consisting almost entirely of ponderosa pine, with many living presettlement trees. There is a large shrub component here, primarily serviceberry and wax currant.

Block 2: This block has a strong Gambel oak component with an abundant herbaceous understory, including sagebrush openings, on basalt soils. This block is similar to a majority of the Mt. Trumbull treatments in the eastern portion of the RCA.

Block 3: At the highest elevation, block 3 is dominated by large, presettlement ponderosa pine, but also has Gambel oak and New Mexican locust throughout the unit. This unit is one of the largest (~100 acres) and is predominately on cinder soils.

Block 4: Block 4 represents the densest stands of ponderosa pine forest at Mt. Trumbull. It consists of dense ponderosa poles, some oak clumps, and some pinyon and juniper at its western end. This block is on basalt soils and has few living presettlement ponderosa pines.

Block 5: This is the lowest elevation block, containing ponderosa pine mixed with pinyon pine and Utah juniper on basalt soils. This has the most diverse herbaceous component, most likely due to the lower elevation and pinyon/juniper component.

Pictures representative of each block are presented in Appendix B.

EXPERIMENTAL BLOCK MONITORING PLOTS

Long-term monitoring is essential to assess current conditions, reconstruct presettlement ecosystem structure, and evaluate the effects of restoration treatments. The standard experimental block monitoring plot is 0.04 ha (0.1 acre) circle (diameter = 22.56 meters), designed with permanent markers to be a long-term monitoring unit. Rebar stakes mark the center origin. The plot design measures various components of forest structure, including trees, shrubs, herbaceous plants, forest floor fuels, canopy closure, and photographic records.

Plot origin was determined from a systematic 60-meter grid placed over the sampling site. Twenty gridpoints that fell within the monitoring type were determined as plot origins. The grid was centered in each experimental block unit (treatment or control). The monitoring type specified for this project is ponderosa pine, with at least 10% ponderosa pine forest cover in presettlement times, based on the presence of presettlement-era trees, snags, stumps, or logs. In mixed species stands, ponderosa pine must have been a dominant tree in the stand with old individuals (or remnants) present. A total of 20 plots were sampled per unit, 40 plots per block.

In addition to the larger plot, the experimental block plot has an inner circle with diameter of 11.28 meters (100m²) for data sampling purposes and is adjusted for slope in the field. Data collection is divided into 7 major areas, as described below.

1. Tree data. All trees greater than breast height were censused on the entire plot

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(0.04 ha). Each tree censused was tagged and the following data was recorded: diameter at breast height, condition, damage, presettlement/postsettlement field call. Presettlement calls were conservative in the field, and based on a minimal diameter in addition to tree bark color, to ensure any potential presettlement live tree was cored. More accurate calls are made in the lab, after dendrochronological analysis to determine pith date (starting year). All live trees called presettlement in the field were cored, and 10% of all post-settlement live trees were cored for age-distribution data. Regeneration (trees below breast height) was censused in the 100m² inner circle within the plot. Species, condition and height were recorded for each seedling.

2. Dead and downed fuel loadings were collected on each plot using planar transects (Brown 1974). Fuel load by size class (i.e., tons/acre of woody fuels by time-lag fuel moisture size classes: 0 - 1/4 in., 1/4 - 1 in., 1 - 3 in., 3+ in rotten and 3+ in sound), and duff and litter depths were collected along a 50 ft planar transect randomly placed starting from the plot origin.

3. Herbaceous data. The point intercept method was used along a 50 m transect placed through the center of the plot, parallel with the slope. At every 30 cm along this 50 m transect, herbaceous species, species height and substrate were recorded, for a total of 166 points per transect.

4. Shrub data. Shrubs were tallied in the 100m² inner circle by species, condition, and height.

5. Tree canopy cover. The point intercept method was used every 30 cm along the 50 m herbaceous transect (as above, total 166 points) to measure presence or absence of tree canopy.

6. Photopoints. Two photopoints were established at each plot, one from north to center of plot, one from east to center of plot.

7. Reference tree: For each plot, a presettlement-era live tree was tagged with the distance and bearing to the plot origin. In case rebar is lost or difficult to find after treatment, a tree which would be retained in the restoration treatment (any tree of presettlement origin is a leave tree) is selected to help relocate the plot origin.

EXPERIMENTAL BLOCK SAMPLING

In 1996 and 1997, 20 plots in each unit (total 40 plots per block) were established in all five experimental blocks. Each block is analyzed separately. All data in this report is **pre-treatment**, i.e., no treatment has been implemented. In most cases, data are presented for treatment and control units separately, to assess the similarity of units prior to treatment. However, for herbaceous and shrub data, results are by block. Data were collected and will be presented in metric units, with corresponding conversions to English units provided in Appendix C.

RESULTS

Contemporary forest conditions, including herbaceous composition, overstory tree structure, tree regeneration, tree canopy cover, forest fuels (coarse woody debris) and forest floor biomass, are presented first for each block. These data will be used to reconstruct the forest stand at the time of the last widespread fire (1870), although not presented in this report. These “presettlement” forest conditions serve as point of reference for natural forest structure and as a guide to planning and evaluating ecological restoration treatments (Covington and Moore 1994a, Covington et al. 1997).

CONTEMPORARY FOREST CONDITIONS

1. CONTEMPORARY HERBACEOUS COMPOSITION AND DENSITY

To assess the similarity of plots within blocks, the entire herbaceous community was analyzed using non-metric multi-dimensional scaling. This method groups sample data in ordination space, based on how similar the sample points are to one another. What we would like to see is that data from within a block group together, and are separate from data from other blocks. Because all data is pre-treatment, the “treatment” plots should be very similar to the “control” plots. The more similar these two units are, the stronger the post-treatment comparisons will be.

Figure 2 shows the ordination results. Squares represent the control unit of each block, triangles represent the treatment (untreated) unit of every block. Different shadings represent different blocks. In every block, there is sufficient overlap between control plots and treatment plots to suggest the control and treatment units are very similar. In addition, the blocks separate out from each other, which justifies using this blocked design with respect to the herbaceous community. For example, block 3 (dark gray with no border) and block 5 (black) are on opposite sides of the ordination. These blocks correspond to the lowest (5) and highest (3) elevation blocks, and have very different herbaceous communities (see also Table 1, most common species).

Overlapping blocks include block 1 with block 4, and block 4 with block 5. Block 4 has a dense pole component, with high accumulations of litter and duff, resulting in little to no herbaceous cover. Block 1 is on the lava flow, and has little litter cover, and very low herbaceous abundance. This might explain why the ordination places these two blocks with some overlap. The overlap of block 4 with 5 can be explained by the pinyon pine and juniper component. Block 4 has 5-6 plots falling in pinyon/juniper, and these plots may have a herbaceous community more similar to block 5 herbaceous community, which has a larger pinyon/juniper component.

Finally, two vectors are placed on this ordination, species richness and Simpson’s diversity index. These vectors explain some of the variation used to plot these points in ordination space. For example, species richness goes through the cloud of points from block 2, which correspondingly had the highest richness and abundance of plants. The diversity vector

goes in a similar direction, but leans towards the block 5 clump. Block 5 actually had a higher diversity of plant species, although the plants were not abundant.

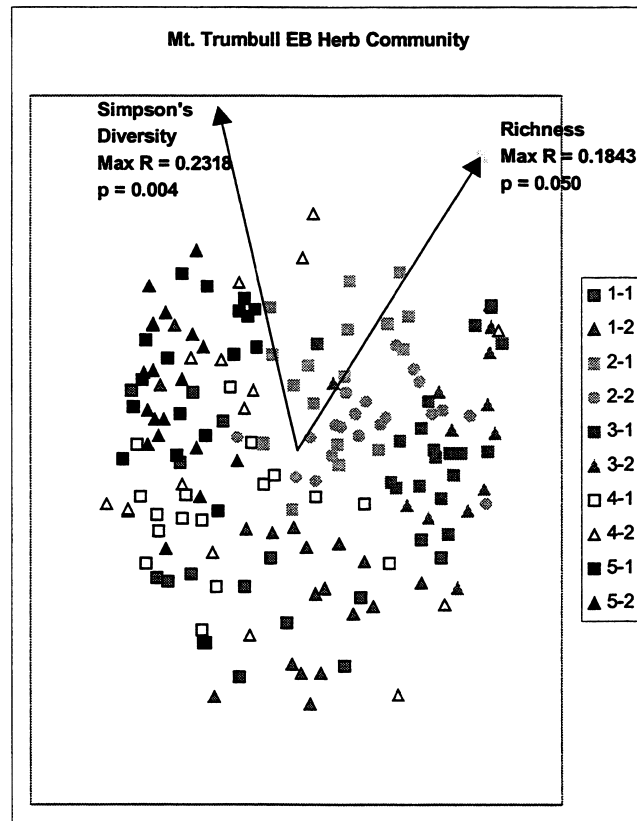


Figure 2: Ordination of herbaceous communities

These ordination results suggest that herbaceous data can be presented by block, because of the similarity of the treatment units within block. Therefore, the remaining herbaceous analyses will be presented by block.

Substrate cover: The majority of ground cover at the Mt. Trumbull experimental blocks is litter, ranging from 64% to 78% of the ground cover (Figure 3). The blocks show consistently low plant cover, usually less than 10%, except for block 2, where plant cover accounts for almost 24% of the forest floor. Bare mineral soil, wood, rock and duff were also present; combined they represented the remaining 18% - 20% of ground cover in each block.

Presettlement ground cover was probably reverse of this pattern, with herbaceous plant material accounting for a much larger percentage of cover; although the exact amount is not known (Cooper 1960, Madany and West 1983, Covington and Sackett 1984, Covington and Moore 1994a).

It is interesting to note the similarity of these data between blocks, even with the community differences shown above in the ordination and the tree density and composition differences shown below. The broad, underlying pattern at Mt. Trumbull is low herbaceous cover, regardless of soil type and contemporary tree composition.

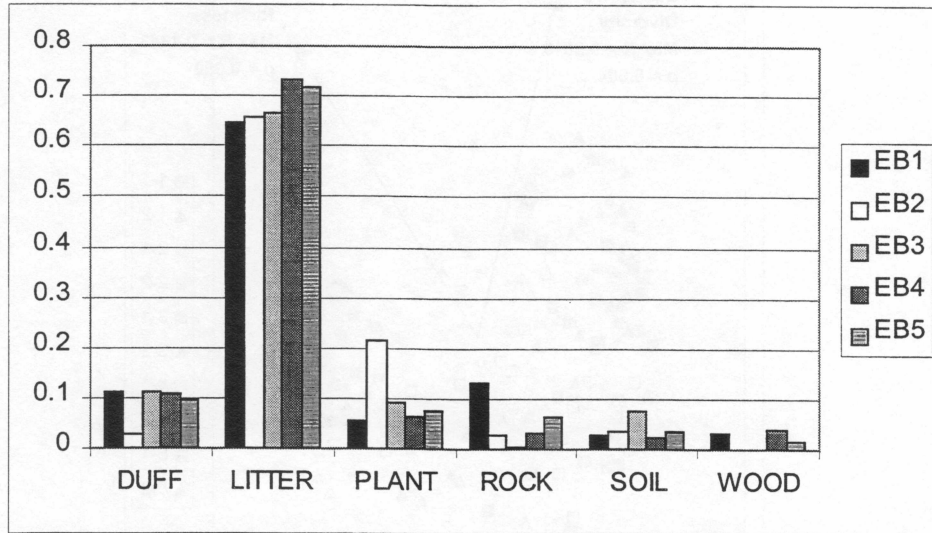


Figure 3. Ground cover by substrate

Plant diversity and richness: Plant diversity and richness is presented in Table 1. These variables parallel the ordination vectors (Figure 2) and cover (Figure 3), with highest richness (or total number of species) found in block 2, and highest diversity (a combination of richness and abundance) found in block 5. Overall species richness is low, with an average of 2 – 6 species found on each plot. Diversity is based on Simpson's diversity index, high values are commonly above 8, although there is no upper limit.

Table 1. Simpson's diversity and species richness.

EB	Average Diversity	Range of Diversity	Average Richness	Range of Richness
1	1.9	0 - 5.8	2.8	0 - 10
2	3.5	0 - 15	6.3	0 - 15
3	1.9	0 - 8.3	2.5	0 - 14
4	2.2	0 - 12	2.5	0 - 9
5	4.5	0 - 28	3.7	0 - 12

Plant composition differed between the five blocks. The 10 most frequent species found are listed in Table 2, by block. Block 1 contains the majority of the shrubs, including Utah serviceberry (*Amelanchier utahensis*), wax currant (*Ribes cereum*), buckbrush (*Ceanothus fendleri*), sagebrush (*Artemisia tridentata*) and Saskatoon serviceberry (*Amelanchier alnifolia*). The high diversity and richness found in block 2 and 5 are also obvious; these blocks have less shrub species and many different forbs and grass species. The herbaceous community in block 4, which is the least diverse, is composed primarily of resilient grass species, including *Carex occidentalis* and *Poa spp.*

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Table 2. Ten most frequent species. (* denote exotic species)

Block 1	Block 2	Block 3	Block 4	Block 5
<i>Amelanchier utahensis</i>	<i>Sitanion hystrix</i>	<i>Artemisia tridentata</i>	<i>Carex occidentalis</i>	<i>Poa fendleriana</i>
<i>Ribes cereum</i>	<i>Lupinus argenteus</i>	<i>Sitanion hystrix</i>	<i>Poa pratensis</i> *	<i>Carex occidentalis</i>
<i>Ceanothus fendleri</i>	<i>Bromus tectorum</i> *	<i>Lupinus argenteus</i>	<i>Poa fendleriana</i>	<i>Poa pratensis</i> *
<i>Poa fendleriana</i>	<i>Artemisia tridentata</i>	<i>Elymus trachycaulus</i>	<i>Amelanchier utahensis</i>	<i>Collinsia parviflora</i>
<i>Artemisia tridentata</i>	<i>Collinsia parviflora</i>	<i>Penstemon pachyphyllus</i>	<i>Sitanion hystrix</i>	<i>Phlox longifolia</i>
<i>Carex occidentalis</i>	<i>Carex occidentalis</i>	<i>Polygonum sp.</i>	<i>Collinsia parviflora</i>	<i>Allium bisceptrum</i>
<i>Monardella odoratissima</i>	<i>Phlox gracilis</i>	<i>Machaeranthera canescens</i>	<i>Phlox longifolia</i>	<i>Penstemon linarioides</i>
<i>Amelanchier alnifolia</i>	<i>Allium bisceptrum</i>	<i>Euphorbia lurida</i>	<i>Poa sp.</i>	<i>Arabis fendleri</i>
<i>Sitanion hystrix</i>	<i>Gayophytum diffusum</i>	<i>Lotus wrightii</i>	<i>Lupinus kingii</i>	<i>Lomatium foeniculaceum</i>
<i>Penstemon rostriflorus</i>	<i>Poa fendleriana</i>	<i>Poa fendleriana</i>	<i>Artemisia tridentata</i>	<i>Amelanchier utahensis</i>

Plant Nativity: Some species of the most frequent groups were exotics (*Bromus tectorum* and *Poa pratensis*). However, native plant species were the major component of the understory structure, as apparent from Table 2 (* denote the exotic species). Exotic plants occurred in the top 10 species only once in blocks 2, 4 and 5, and not at all in blocks 1 and 3. Native species accounted for between 82% (block 3) and 97% (block 5) of all species encountered in the blocks. A complete herbaceous and wood plant species list, by family, is provided in Appendix A.

Shrub composition: Total shrubs are presented by block in Table 3. Although blocks 2 and 3 have by far the largest number of shrubs, sagebrush (*Artemisia tridentata*) is the dominant component, totaling 99% of the shrub community. Block 1 has the most diverse shrub community, with a total of 9 shrub species, more evenly distributed.

Table 3. Shrubs per hectare

Block	# of species	Shrubs per ha (s.e.)
1	9	632.5 (113.6)
2	4	1657.5 (509.3)
3	2	1385 (424.8)
4	5	382.5 (176.4)
5	5	425 (183.1)

Sample collections of plants were brought back to NAU. Unknown species were identified and representatives of all species were mounted on herbarium sheets and prepared for storage. Mounted specimens were provided to the BLM AZ Strip District and also to the Deaver Herbarium at NAU. These collections represent a substantial new contribution to knowledge about the herbaceous component of the forest ecosystem in the Mt. Trumbull area.

2. CONTEMPORARY FOREST OVERSTORY STRUCTURE

Density and Basal Area

The five experimental blocks were chosen to represent the different ponderosa pine forest types found at the Mt. Trumbull RCA. The current forest conditions show these differences in species composition, basal area and density (Tables 4-8). These data are

presented by treatment unit (treatment or control), to clearly display similarity and differences within blocks, as well as between blocks.

Blocks 1 and 3 have the lowest basal area; these blocks are unique with low densities and high numbers of large diameter, presettlement trees. Block 4 has the highest basal area. Although this block does not have many living presettlement trees, the extremely high numbers of small diameter trees can contribute to a high basal area (Table 4). Basal area results also demonstrate that while the blocks have different tree components, all blocks are dominated by ponderosa pine. Between block differences are generally greater than within block differences.

Table 4. Basal Area, live trees only (m² per ha (s.e.)). To convert to ft²/acre, multiply by 4.355.

Block		Total	Utah Juniper	Pinyon Pine	Ponderosa Pine	Gambel oak	New Mexican Locust
1	Control	26.9 (2.3)	0	< 0.01	26.7 (2.4)	0.23 (0.21)	0.02 (0.02)
	Treatment	23.7 (1.7)	0	0	23.2 (1.7)	0.49 (0.36)	0
2	Control	36.1 (2.8)	0.11 (0.07)	0	31.6 (2.7)	4.4 (0.92)	0.03 (0.03)
	Treatment	39.6 (4.3)	0.01 (0.01)	0.04 (0.04)	38.2 (4.5)	0.99 (0.44)	0.43 (0.42)
3	Control	30.4 (3.8)	0.09 (0.09)	0.18 (0.09)	29.5 (3.9)	0.58 (0.31)	0.04 (0.02)
	Treatment	39.6 (4.3)	0.01 (0.01)	0.04 (0.04)	38.2 (4.5)	0.99 (0.44)	0.43 (0.42)
4	Control	45.2 (3.1)	4.6 (1.9)	1.1 (0.9)	38.3 (3.7)	1.2 (0.40)	<0.01
	Treatment	50.3 (1.8)	2.3 (0.52)	0.43 (0.29)	46.2 (2.1)	1.3 (0.32)	<0.01
5	Control	37.9 (2.2)	0.90 (0.23)	0.06 (0.02)	35.5 (2.4)	1.4 (0.50)	<0.01
	Treatment	30.0 (2.4)	2.9 (0.46)	0.34 (0.12)	25.7 (2.4)	1.0 (0.31)	<0.01

Total live trees per hectare are presented in Table 5. The differences between blocks found in basal area are paralleled in this table. What is more apparent are differences within blocks in stems per hectare. Block 2 has almost a 400-tree/ha difference between the control and treatment units. However, the standard errors are large for both units, meaning both units have high variability in tree density. Block 5 also has a large difference in tree density between control and treatment units. These units also have a large amount of variation, but the oak densities are higher in the control unit. The other three blocks show no major differences between control and treatment units.

Snag densities (Table 6) are very similar within blocks. The highest snag densities are found in blocks with a large oak component, blocks 2 and 5 and in block 4, with the highest ponderosa pine density. However, 60% - 80% of these snags are below 20-cm (7.8") dbh. Dead and down trees (Table 7) can be variable throughout a landscape, but also show greater differences between the blocks than within the blocks. Finally, cut stumps (Table 8) show little wood removal in blocks 1 and 3, because these areas are hard to access and have steep topography. Accordingly, these blocks have the highest numbers of presettlement trees.

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The cut stump class includes cut small diameter trees, as well as larger merchantable wood. It is interesting to note the amount of oak that has been cut off the site.

Table 5. Live trees per hectare (standard error). To convert to trees/acre, multiply by 0.4047.

Block		Total	Utah Juniper	Pinyon Pine	Ponderosa Pine	Gambel oak	New Mexican Locust
1	Control	691.3 (93.7)	0	1.3 (1.3)	608.8 (89.6)	70 (54.8)	11.25 (11.25)
	Treatment	593.8 (100.2)	0	0	477.5 (78.7)	116.3 (80.8)	0
2	Control	1373.8 (233.9)	13.75 (8.9)	0	681.3 (108.0)	610 (172.9)	68.75 (32.84)
	Treatment	1722.5 (421.6)	2.5 (1.7)	6.25 (3.57)	276.3 (70.5)	507.5 (128.7)	930 (456.3)
3	Control	948.8 (191.4)	1.25 (1.25)	6.25 (3.1)	507.5 (134.2)	43.8 (22.9)	390 (171.4)
	Treatment	876.3 (127.7)	1.25 (1.25)	1.25 (1.25)	620 (124.0)	52.5 (29.2)	201.3 (100.5)
4	Control	2472.5 (197.7)	250 (57.5)	122.5 (33.4)	1662.5 (255.1)	411.3 (91.1)	26.3 (15.2)
	Treatment	2347.5 (159.5)	191.3 (37.9)	37.5 (12.9)	1710 (153.0)	395 (110.9)	13.8 (10.2)
5	Control	2910 (288.4)	113.8 (19.3)	40 (11.1)	1671.3 (195.8)	1062.5 (336.3)	22.5 (12.0)
	Treatment	1808.8 (138.7)	326.3 (65.0)	46.3 (7.3)	882.5 (124.5)	551.3 (121.1)	2.5 (2.5)

Table 6. Snags per hectare (standard error). To convert to trees/acre, multiply by 0.4047.

Block		Total	Utah Juniper	Pinyon Pine	Ponderosa Pine	Gambel oak	New Mexican Locust
1	Control	27.5 (8.9)	0	0	16.3 (6.1)	6.3 (4.0)	5 (5)
	Treatment	33.8 (15.2)	0	0	13.8 (7.8)	20 (14.1)	0
2	Control	370 (116.3)	0	0	30 (11.4)	333.8 (119.6)	6.3 (4.4)
	Treatment	421.3 (103.0)	0	0	3.8 (2.0)	220 (60.0)	197.5 (103.5)
3	Control	210 (100.1)	0	0	12.5 (5.0)	22.5 (12.2)	175 (92.6)
	Treatment	110 (34.4)	0	0	16.3 (7.8)	55 (29.7)	38.8 (21.6)
4	Control	871.3 (112.1)	32.5 (12.0)	6.3 (3.1)	128.8 (38.6)	683.8 (124.6)	20 (9.9)
	Treatment	893.8 (137.9)	7.5 (5.2)	1.3 (1.3)	101.3 (23.8)	767.5 (130.3)	16.3 (11.4)
5	Control	818.8 (122.0)	1.3 (1.3)	0	38.8 (20.1)	766.3 (114.0)	12.5 (7.8)
	Treatment	373.8 (82.9)	13.8 (4.6)	0	23.8 (15.2)	336.3 (82.5)	0

Table 7. Dead and Down per hectare (s.e.). To convert to trees/acre, multiply by 0.4047.

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Block		Total	Utah Juniper	Pinyon Pine	Ponderosa Pine	Gambel oak	New Mexican Locust
1	Control	33.8 (10.1)	0	0	23.8 (5.3)	10 (10.0)	0
	Treatment	47.5 (14.4)	0	0	41.3 (14.0)	6.3 (6.3)	0
2	Control	111.3 (25.0)	0	0	32.5 (7.9)	78.8 (25.0)	0
	Treatment	50 (11.0)	0	0	3.8 (2.0)	35 (10.3)	11.3 (7.8)
3	Control	18.8 (6.8)	0	0	8.8 (4.5)	2.5 (2.5)	7.5 (5.5)
	Treatment	42.5 (12.0)	0	0	32.5 (12.2)	5 (3.9)	5 (3.9)
4	Control	442.5 (89.7)	5 (3.9)	1.3 (1.3)	141.3 (45.1)	293.8 (81.1)	1.3 (1.3)
	Treatment	523.8 (91.4)	16.3 (13.7)	0	98.8 (25.7)	406.3 (84.5)	2.5 (2.5)
5	Control	196.3 (47.4)	1.3 (1.3)	0	21.3 (7.5)	173.8 (45.1)	0
	Treatment	192.5 (45.8)	5 (2.9)	0	37.5 (18.1)	150 (47.6)	0

Table 8. Cut Stumps per hectare (s.e.). To convert to trees/acre, multiply by 0.4047.

Block		Total	Utah Juniper	Pinyon Pine	Ponderosa Pine	Gambel oak	New Mexican Locust
1	Control	1.3 (1.3)	0	0	1.3 (1.3)	0	0
	Treatment	2.5 (2.5)	0	0	0	2.5 (2.5)	0
2	Control	31.3 (18.8)	0	0	16.3 (5.8)	15 (15.0)	0
	Treatment	28.8 (17.0)	0	0	7.5 (5.2)	21.3 (16.7)	11.3 (7.8)
3	Control	0	0	0	0	0	0
	Treatment	2.5 (1.7)	0	0	2.5 (1.7)	0	0
4	Control	5 (3.4)	0	0	5 (3.4)	0	0
	Treatment	3.8 (2.0)	0	0	2.5 (1.7)	1.3 (1.5)	0
5	Control	48.8 (17.8)	0	0	28.8 (11.2)	20 (14.3)	0
	Treatment	53.8 (18.2)	2.5 (2.5)	0	27.5 (10.2)	23.8 (16.6)	0

Diameter Distributions

Diameter distributions are presented below for live trees only from all blocks (Figures 4 – 8). Diameter distributions show that at least 50% of live trees are less than 20-cm (7.8”) dbh on all blocks. Of these smaller trees, pines are the major component in blocks 1, 3 and 4. In blocks 2 and 5, Gambel oak (QUGA) and New Mexican locust (RONE) are major components of the small diameter classes. Numbers of non-ponderosa pine species drop off at the higher diameter classes. The largest ponderosa pine (PIPO) trees were found on block 3, with trees in each unit in the 105-cm (41”) diameter class.

The control and treatment units within blocks have very similar diameter distributions. Some differences do occur in blocks 2 and 5, as in above density section. These differences in density occur at the smallest diameters, however, explaining the lack of difference in the basal area between units. Differences between blocks do occur in tree composition and density. Block 5 has the highest density of small diameter oaks, while block 2 has the largest component of New Mexican locust.

Legend: RONE – New Mexican Locust, QUGA – Gambel oak, PIPO – ponderosa pine, PIED – pinyon pine, JUOS – Utah juniper. DBH is the midpoint of 10-cm diameter classes.

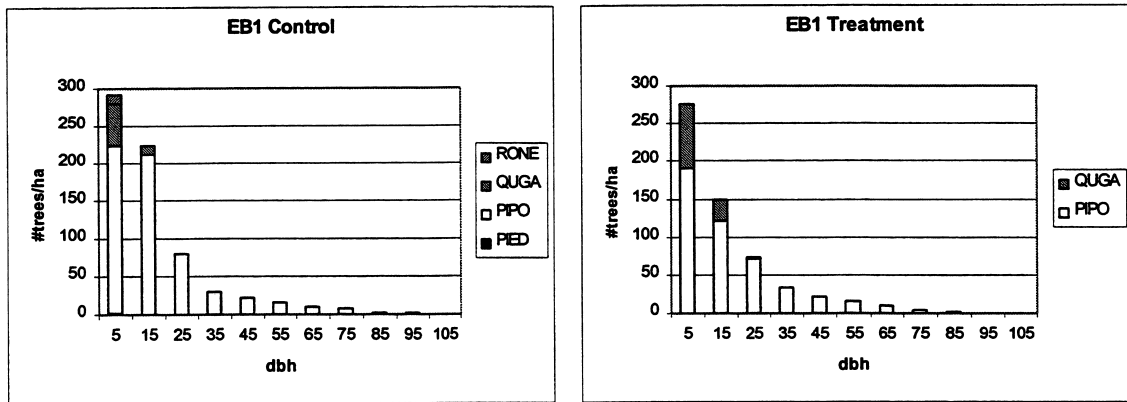


Figure 4. Block 1 Diameter Distribution, Control and Treatment

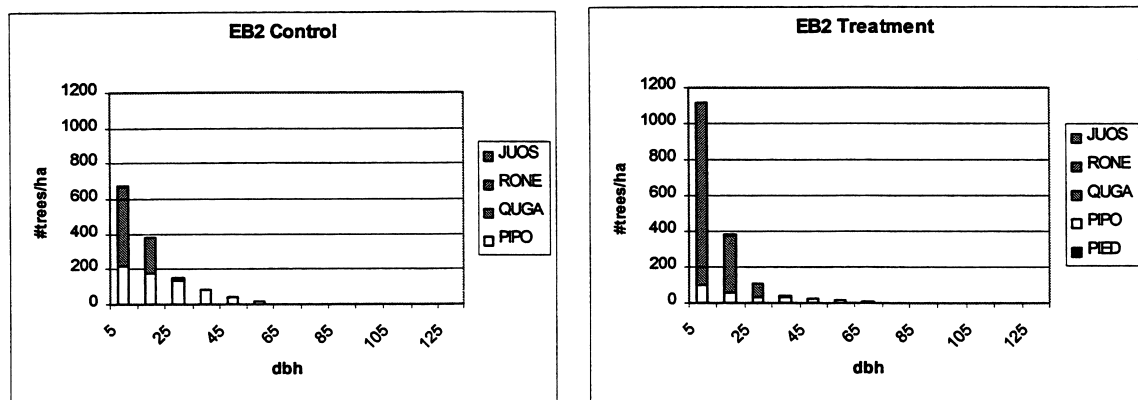


Figure 5. Block 2 Diameter Distribution, Control and Treatment

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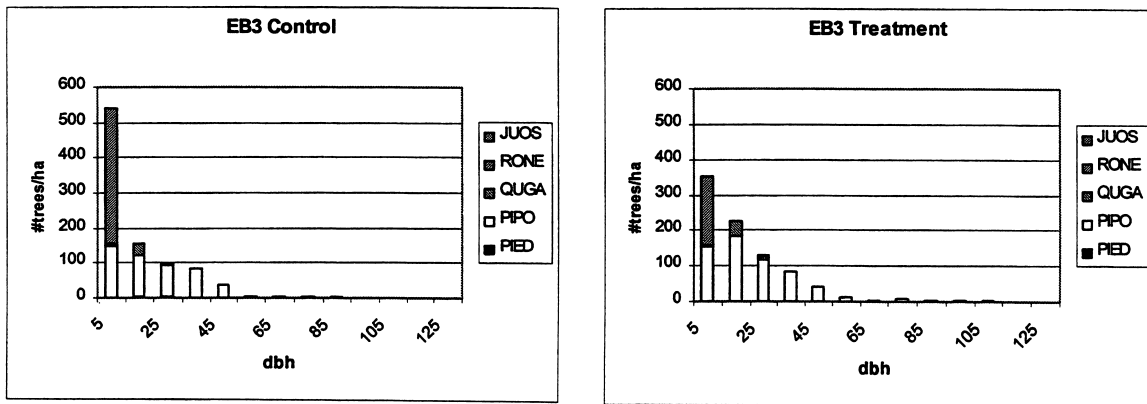


Figure 6. Block 3 Diameter distribution, Control and Treatment

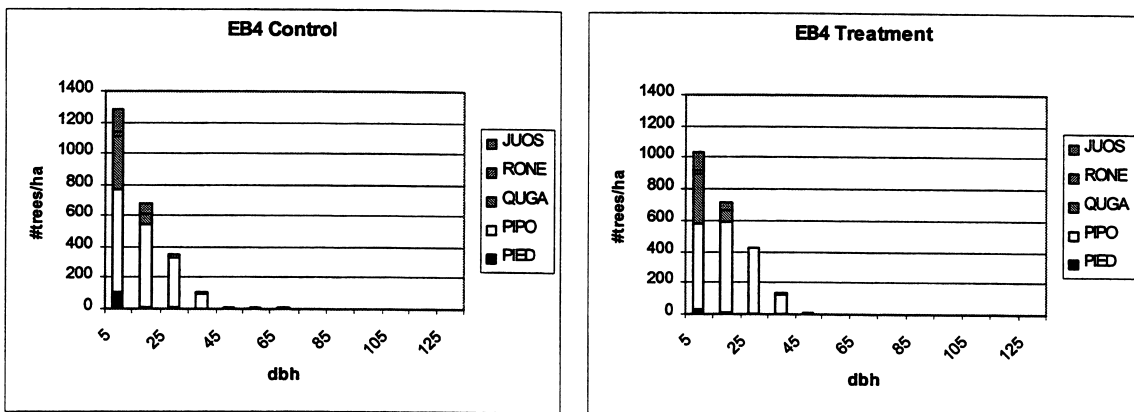


Figure 7. Block 4 Diameter distribution, Control and Treatment

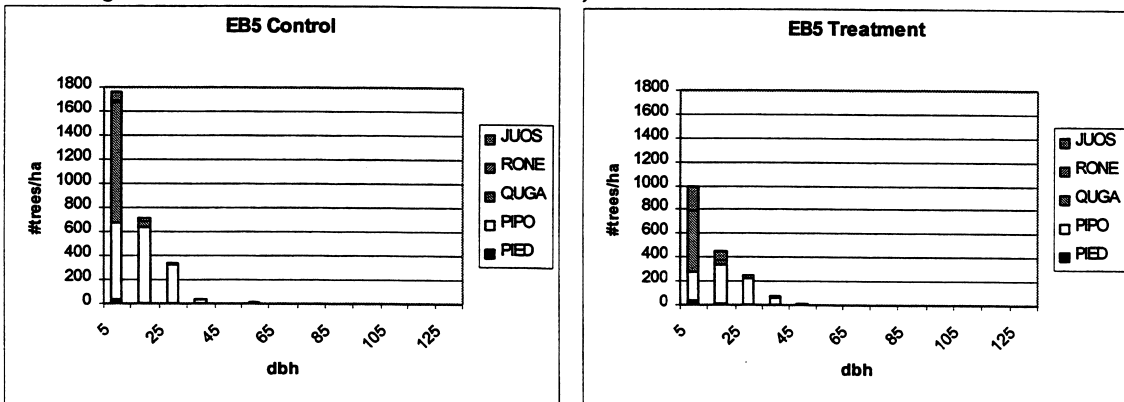


Figure 8. Block 5 Diameter distribution, Control and Treatment

Age Distribution

Tree increment cores were mounted and surfaced in the lab, and then dated using dendrochronological methods and chronologies from the Mt. Trumbull area (Stokes and Smiley 1968). The age distribution is shown in Figures 9-13 from 1410 to 1990, with center dates at 40 cm (15.75") sampling height. The center dates represent the center point of a 20-year age class. For example, the 1910 tally represents all trees reaching the 40-cm coring height between 1901 and 1920.

Large pulses of Gambel oak appeared in the late 1800's, following the last fire, which occurred around 1870 across the area (Waltz and Fulé 1998). Large pulses of ponderosa pine can be seen between 1901 and 1940, mirroring similar patterns found in ponderosa pine forests across the southwest. This is probably associated with good cone crops and large regeneration events occurring from 1915 - 1925. In blocks 2 -5, there is also a large pulse of regeneration in the last 20-40 years. This is primarily due to New Mexican Locust (RONE) and Gambel oak (QUGA). These species are opportunistic seeders, and oaks can regenerate through suckering from roots. In addition, both species show evidence of self-thinning, which may explain why we only see this recent pulse of regeneration since the 1960's.

Because of the high density of postsettlement trees, the trees established before the turn of the century do not even appear on these graph scales. However, the oldest trees were found in block 3, with trees dating back to 1417. This site is located on steep, cinder soils, which may have been more difficult to access and harvest than some of the lower sites. Block 1 also had trees dating back to the 15th century, and similarly was found on lava soils, difficult to access. The other three blocks' oldest living trees dated back to the 1600's. Living presettlement trees were primarily ponderosa pine. A small portion of living presettlement trees were oaks, and presettlement pinyon pine and juniper were found in small numbers in blocks 4 and 5 only.

Legend: PIPO – ponderosa pine; QUGA – Gambel oak; RONE – New Mexican Locust; PIED – pinyon pine; JUOS – Utah juniper

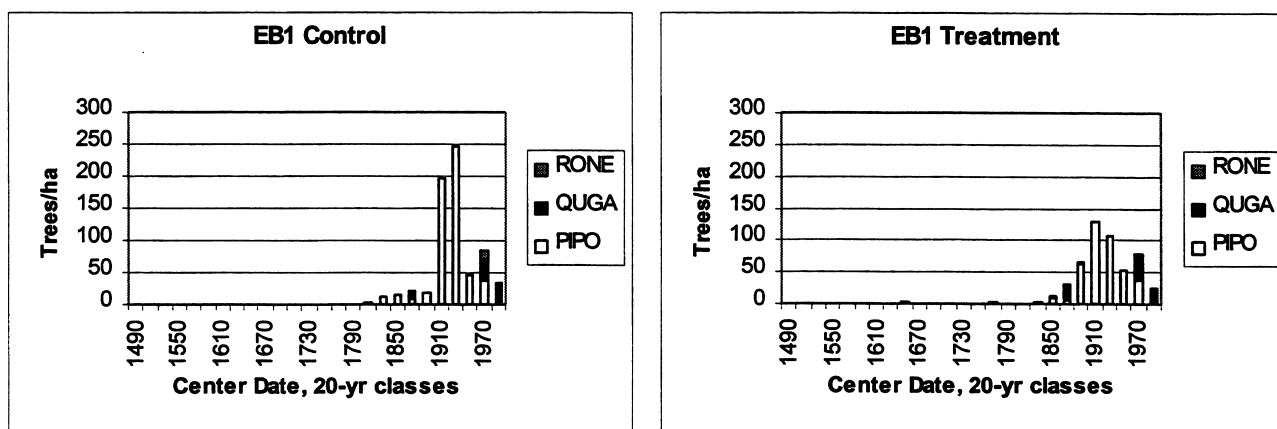


Figure 9. Block 1 Age Distribution, Control and Treatment Units.

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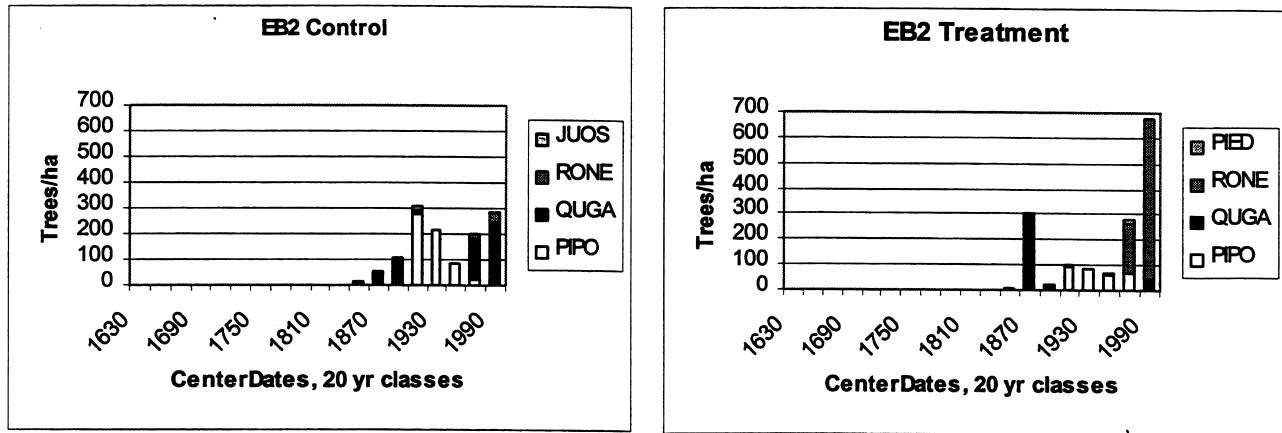


Figure 10. Block 2 Age Distribution, Control and Treatment Units.

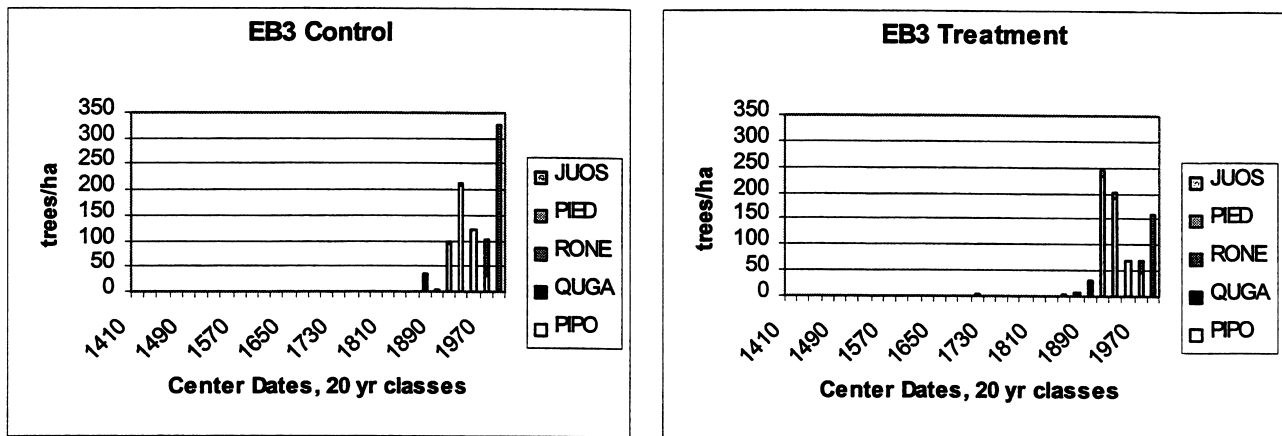


Figure 11. Block 3 Age Distribution, Control and Treatment Units.

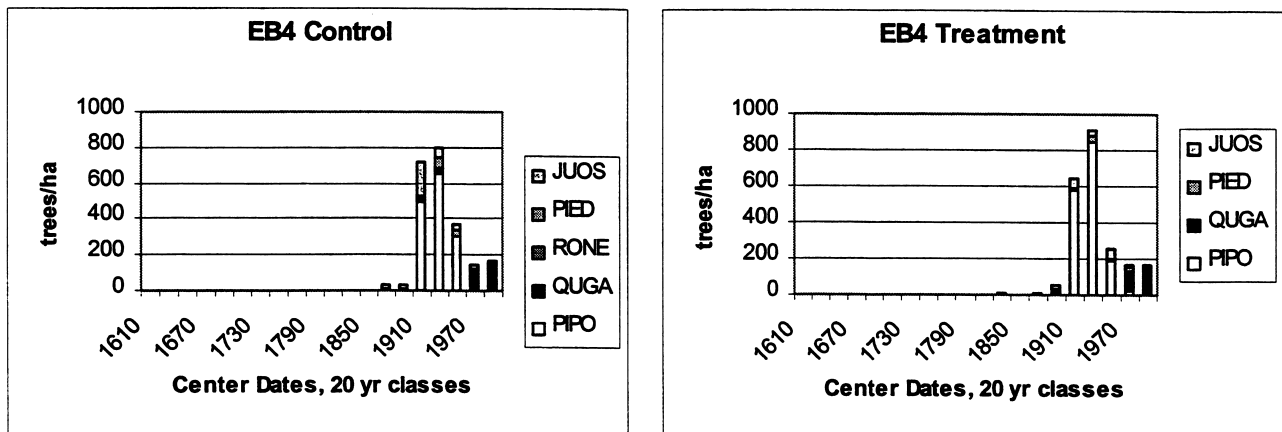


Figure 12. Block 4 Age Distribution, Control and Treatment Units.

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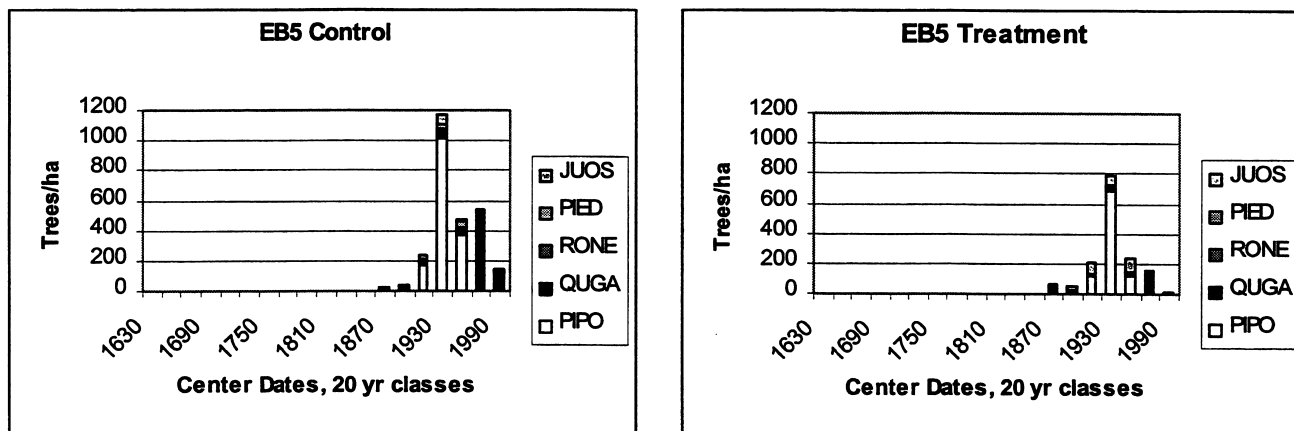


Figure 13. Block 5 Age Distribution, Control and Treatment Units.

3. TREE REGENERATION

Tree regeneration in the experimental blocks is summarized in Table 9. The most frequent seedling or sprout was Gambel oak in all blocks except block 3. The dominant seedling in block 3 was New Mexican Locust. Block 5 has the highest number of seedlings in the control unit. These numbers are composed almost entirely of Gambel oak seedlings, often found growing in clumps. The variance is very large for this unit, implying there is a large range in the numbers of oaks commonly found. Ponderosa pine seedlings had very low densities in all blocks, ranging only from 20 to 160 seedlings/ha.

Table 9. Tree regeneration per hectare (s.e.)

Block	Control	Treatment
1	125 (33.1)	380 (160.2)
2	4,435 (1,434)	4,295 (1,290.1)
3	2,330 (1,043.2)	805 (393.7)
4	4,215 (1,491.8)	5,810 (1,625.1)
5	17,180 (5,238.8)	3,765 (1,050.9)

4. TREE CANOPY COVER

Tree canopy cover averaged 50% on all plots sampled across all blocks (Table 10). These cover estimates are more than twice the 15% - 25% canopy cover estimated in presettlement times in similar forests (Pearson 1950, Covington and Sackett 1984, Covington et al. 1997). Blocks 1, 2 and 3 had the lowest canopy cover, corresponding to the lower tree densities found in those blocks. Block 4 had the highest canopy cover of any site the Ecological Restoration Program has censused, corresponding to the high tree densities found there.

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Table 10. Canopy Cover %

Block	Control	Treatment
1	50.6 (2.9)	35.6 (2.9)
2	62.7 (3.2)	55.5 (4.1)
3	47.6 (4.5)	49.3 (4.8)
4	70.5 (2.5)	74.4 (3.6)
5	61.7 (3.9)	53.6 (2.7)

5. FUELS— COARSE WOODY DEBRIS AND FOREST FLOOR BIOMASS

Average pre-treatment fuel loadings were 26 tons per acre on all blocks (Table 11). However, these vary considerably between experimental blocks. Most blocks are above the 10-tons/acre average in southwestern ponderosa pine forests (Sackett 1979). In terms of potential fire behavior, continuous fuels to carry the flaming front are found throughout the study area, but coarse woody debris— the heavier fuels that can lead to more intense soil heating— are more variable in distribution. These heavier fuels are variable within blocks as well as between blocks.

Table 11. Coarse woody fuels (tons/acre (s.e.)).

Block		1-hour	10-hour	100-hour	1000-h Sound	1000-h Rotten	Total
1	Control	0.31 (0.13)	0.85 (0.17)	1.47 (0.47)	8.10 (4.82)	1.81 (1.47)	12.5 (4.85)
	Treatment	0.10 (0.04)	0.40 (0.06)	0.70 (0.38)	21.8 (12.5)	5.62 (3.65)	28.6 (12.6)
2	Control	0.10 (0.03)	0.81 (0.27)	1.28 (0.33)	6.45 (3.79)	6.15 (4.42)	14.8 (5.44)
	Treatment	0.10 (0.03)	0.63 (0.11)	1.09 (0.30)	19.1 (17.9)	3.69 (3.27)	24.6 (21.1)
3	Control	0.15 (0.04)	1.04 (0.18)	0.96 (0.38)	6.19 (4.15)	4.10 (2.58)	12.4 (6.38)
	Treatment	0.06 (0.02)	0.67 (0.19)	0.71 (0.22)	1.80 (0.72)	4.13 (2.51)	7.36 (2.64)
4	Control	0.20 (0.06)	1.18 (0.27)	1.66 (0.72)	4.59 (2.09)	2.09 (1.69)	9.70 (3.13)
	Treatment	0.18 (0.05)	1.07 (0.25)	1.60 (0.52)	9.39 (5.17)	0.80 (0.80)	13.0 (5.51)
5	Control	0.17 (0.04)	0.87 (0.17)	0.38 (0.16)	3.20 (1.61)	5.45 (4.07)	10.1 (5.23)
	Treatment	0.12 (0.03)	0.50 (0.14)	0.83 (0.25)	6.23 (4.81)	0.20 (0.13)	7.87 (4.86)

CONCLUSIONS

CONTEMPORARY FOREST CONDITIONS

The range of conditions reported for the five experimental blocks at Mt. Trumbull is similar to that of many ponderosa pine forests in northern Arizona. However, each block represents a different portion of the range, encompassing different soil types, tree composition, tree density and herbaceous cover. The Mt. Trumbull Resource Conservation Area is ideal for this experimental block design because of the range of conditions found on this relatively

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small forested area. Lava flows, cinder soils, basalt soils, different logging and grazing intensities have all combined to produce these different forest types that will most likely respond differently to the restoration treatment. Because of this design, the results obtained from the paired blocks will explain a range of responses to restoration treatment.

In the blocks with highest tree densities, primarily blocks 2, 4 and 5, the thinning component of the restoration treatment may have the most drastic impact on the system. However, even within these three blocks, the high densities are due to different tree species. Block 2 has a strong component of Gambel oak, while block 5 has the largest component of Utah juniper and pinyon pine. While studies exist showing increased ponderosa pine tree vigor following restoration treatment (Covington et al. 1997, Feeney et al. 1996), little is known about the response of oak, juniper and pinyon pine to restoration treatment. Blocks 2 and 5, with higher proportions of oak (block 2) and pinyon/juniper (block 5) may show different responses to the thinning than block 4.

In blocks 1 and 3, with relatively low tree density, thinning will be minimal. Returning fire to these blocks may have the largest effect on the responses to restoration treatment. This experiment will provide the first studies showing the response of shrub species such as serviceberry and wax currant to ponderosa pine restoration.

The herbaceous community, because of its pre-treatment differences, is also hypothesized to show variations in the response to restoration. Blocks 2 and 5 have a much higher diversity and abundance of herbaceous material than blocks 1, 3 and 4, which may result in faster response of the herbaceous community than in the more sparse blocks. These diverse blocks may also see less initial invasion of exotics, as there are existing native seed sources close by.

The blocks with low diversity and abundance (1, 3 and 4) are sparse in their herbaceous communities due to different factors, implying that the response of each of these units to restoration will differ as well. On blocks 1 and 3, the substrate types, lava (block 1) and cinder (block 3), do not have much soil to support high herbaceous densities, although block 1 has the most diverse shrub community. As mentioned above, these areas will need minimal thinning to return them to the range of presettlement tree densities, and then fire will be introduced. Soil availability, and not seed source availability may limit revegetation on these two blocks. Block 4, however, has a sparse herbaceous community primarily due to high tree densities, and deep litter and duff layers. Thinning followed by burning to expose mineral soil may have a greater impact on the herbaceous community in this block. Existing seed sources may be located far away and it might take longer for a perennial herbaceous community to establish here than in, for example, block 2. We also may see higher initial occurrence of exotics, as this area will incur more disturbance during the restoration treatment than blocks 1 and 3.

OTHER RESEARCH PROJECTS

Other research projects initiated in these experimental blocks are briefly outlined here. Dr. Carol Chambers and master's candidate Heather Shanes are monitoring small mammal populations pre- and post-treatment in the experimental blocks. They additionally have

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monitored the rates of hantavirus in rodent populations, and will continue to examine the affect of restoration treatments on rates of hanta virus infection.

Dr. Thomas Sisk and graduate students are looking at the effects of edges created by restoration treatments on abiotic variables, including temperature, relative humidity and light intensity. In addition, the effects of edges on bird and butterfly populations are being examined. Dr. Wally Covington and Ph.D. candidate Amy Waltz are examining the effects of restoration treatments on the butterfly community at Mt. Trumbull. Butterflies have shown to increase in the restored areas, due to increases in nectar resource.

Mike Elson, and master's student, documented ponderosa pine tree use of the Kaibab squirrel in the experimental blocks with Wally Covington. Finally, an undergraduate research project, headed by Justin Waskiewicz, is examining the usage of snags by birds in the experimental blocks. Snag usage before and after restoration treatments will be compared.

PROPOSED TREATMENT SCHEDULE

These blocks are scheduled to be thinned the summer and fall of 1999, and to be burned in the fall of 1999. Treatment of these units at the same time strengthens the experimental design by supporting direct comparisons of results between blocks.

Block 1 was treated January 1999 by the Bureau of Land Management's fuel crew, headed by Greg Taylor. Blocks 2 and 3 were sold as part of the larger Cinder Sale, and are currently being treated. Block 4 was sold to an individual woodcutter, who plans on commencing work summer of 1999. Block 5 was a difficult block operationally. The original treatment unit in this block was located far from the road, and not easily accessible except possible through the control. As a result, the land managers and researchers agreed to switch the control and treatment units. Therefore, this block does not have randomly assigned treatment and control units. Although this causes some loss of statistical power, it made it possible to actually treat the unit the same year as the other units. The researchers felt this loss of statistical power was worth maintaining five blocks.

Post-treatment remeasurements of the experimental block plots will commence summer of 2000. This initial post-treatment data will be analyzed and presented winter/spring of 2000-01. These units will not be seeded, allowing researchers to follow the natural succession of herbaceous communities due to treatment. Continued monitoring is necessary to fully document the effects of restoration in ponderosa pine communities.

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CONTRIBUTORS

The following people participated in the project implementation, fieldwork, and analysis presented in this report.

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APPENDIX A. HERBACEOUS AND WOODY SPECIES LIST, MT. TRUMBULL, ARIZONA

All species on this list were updated from Kartesz & Kartesz (1994) and the PLANTS Database based on the Flora of North America Project

Family	Species	Common name	Nat'y	Form	Comments/Synonyms
Aceraceae	<i>Acer grandidentatum</i> Nutt.	bigtooth maple	N	T	Wash near EB-4
Amaranthaceae	<i>Amaranthus albus</i> L.	prostrate pigweed	I	A	Adventive from tropical America
Anacardiaceae	<i>Rhus glabra</i> L.	smooth sumac	N	T	Lava Fire
	<i>Rhus trilobata</i> Nutt.	skunkbush sumac	N	S	
Apiaceae	<i>Cymopterus multinervatus</i> (Coult. & Rose) Tidestrom	purplenerve springparsley	N	P	Collected by Cottam, but not NAU
	<i>Cymopterus purpureus</i> S. Wats.	purple springparsley	N	P	Base of MT - p-j zone
	<i>Lomatium foeniculaceum</i> ssp. <i>macdougalii</i> (Coult. & Rose) Theobald	MacDougal's biscuitroot	N	P	Mt. Logan overlook
Asclepiadaceae	<i>Asclepias asperula</i> (Dcne.) Woods.	spider milkweed	N	P	
	<i>Asclepias subverticillata</i> (Gray) Vail	whorled milkweed	N	P	
Asteraceae	<i>Ageratina herbaceae</i> (Gray) King & H.E. Robins.	fragrant snakeroot	N	P	Similar to <i>Brickellia grandiflora</i> , EB-4 wash
	<i>Agoseris glauca</i> (Pursh) Raf.	pale agoseris	N	P	
	<i>Artemisia carruthii</i> Wood ex Carruth.	Carruth's sagewort	N	P	
	<i>Artemisia dracunculus</i> L.	wormwood	N	P	Cottam - Uinkaret Plat. (Check NAU plots)
	<i>Artemisia frigida</i> Willd.	fringed sagewort	N	P	Cottam - Mt. Emma
	<i>Artemisia tridentata</i> Nutt.	big sagebrush	N	S	
	<i>Brickellia eupatorioides</i> var. <i>chlorolepis</i> (Woot. & Standl.) B.L. Turner	false boneset	N	P	<i>Brickellia chlorolepis</i>
	<i>Chaenactis douglasii</i> (Hook.) Hook. & Arn.	Douglas' dustymaiden	N	P	
	<i>Chrysothamnus depressus</i> Nutt.	longflower rabbitbrush	N	S	
	<i>Chrysothamnus viscidiflorus</i> (Hook.) Nutt.	green rabbitbrush	N	S	Cottam - east slope of Mt. Trumbull
	<i>Cirsium wheeleri</i> (Gray) Petrak	Wheeler's thistle	N	P	
	<i>Conyza canadensis</i> (L.) Cronq.	Canadian horseweed	N?	A	Probably introduced
	<i>Erigeron bellidiastrum</i> Nutt.	western daisy fleabane	N	A	Cottam - hill N. of N.S., not coll. by NAU
	<i>Erigeron divergens</i> Torr. & Gray	spreading fleabane	N	P	
	<i>Erigeron flagellaris</i> Gray	trailing fleabane	N	P	
	<i>Erigeron speciosus</i> (Lindl.) DC.	aspen fleabane	N	P	
	<i>Gutierrezia sarothrae</i> (Pursh) Britt. & Rusby	broom snakeweed	N	P	
	<i>Helianthus anomalus</i> Blake	western sunflower	N	A	Cottam - Uinkaret Plateau in pipo
	<i>Heliomeris multiflora</i> var. <i>multiflora</i> Nutt.	showy goldeneye	N	A/P	<i>Viguiera multiflora</i>
	<i>Hymenopappus filifolius</i> Hook.	fineleaf hymenopappus	N	P	

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	<i>Hymenoxys cooperi</i> var. <i>cooperi</i> (Gray) Cockerell	Cooper's hymenoxys	N	P/B	
	<i>Machaeranthera canescens</i> (Pursh) Gray	hoary aster	N	P	
	<i>Onopordum acanthium</i> L.	Scotch cottonthistle	I	P	
	<i>Sanvitalia abertii</i> Gray	Albert's creeping zinnia	N	A	
	<i>Senecio eremophilus</i> var. <i>macdougallii</i> (Heller) Cronq.	Macdougall's groundsel	N	A/P	<i>Senecio macdougallii</i>
	<i>Senecio multilobatus</i> Torr. & Gray ex Gray	lobeleaf groundsel	N	P	
	<i>Solidago velutina</i> DC.	threenerve goldenrod	N	P	<i>Solidago sparsiflora</i>
	<i>Stephanomeria tenuifolia</i> (Raf.) Hall	narrowleaf wirelettuce	N	P	
	<i>Taraxacum officinale</i> G.H. Weber ex Wiggers	common dandelion	I	P	
	<i>Tetradymia canescens</i> DC.	spineless horsebrush	N	P	
	<i>Tetraneuris acaulis</i> var. <i>acaulis</i> (Pursh) Greene (v. <i>arizonica</i> ?)	stemless hymenoxys	N	P	<i>Hymenoxys acaulis</i> - crest of Mt. Logan
	<i>Townsendia incana</i> Nutt.	hoary townsendia	N	P	Cottam?
	<i>Tragopogon dubius</i> Scop.	yellow salsify	I	P	
	<i>Verbesina encelioides</i> (Cav.) Benth. & Hook.f.ex Gray	golden crownbeard	N	A	96-1 after the burn
Berberidaceae	<i>Mahonia fremontii</i> (Torr.) Fedde	Fremont's mahonia	N	S	<i>Berberis fremontii</i>
	<i>Mahonia repens</i> (Lindl.) G. Don	Oregon-grape	N	S	<i>Berberis repens</i>
Boraginaceae	<i>Cryptantha cinerea</i> var. <i>cinerea</i> (Greene) Cronq.	James's catseye	N	P	
	<i>Lappula occidentalis</i> (S. Wats.) Greene	flatspine stickseed	N?	A	May be introduced
	<i>Mertensia macdougallii</i> Heller	Macdougall's bluebells	N	P	Not enough plant mat'l for positive ID
Brassicaceae	<i>Arabis fendleri</i> var. <i>fendleri</i> (S. Wats.) Greene	Fendler's rockcross	N	P/B	
	<i>Chorispura tenella</i> (Pallas) DC.	crossflower	I	A	Logan Burn
	<i>Descurainia californica</i> * (Gray) O.E. Schulz	Sierran tansymustard	N?	A/B	Not enough plant mat'l for positive ID
	<i>Descurainia pinnata</i> ssp. <i>intermedia</i> (Rydb.) Detling	western tansymustard	N?	A	Introduced?
	<i>Draba</i> sp. L.	whitlowgrass	N	A/B	One spec. in 96-1 after burn, not coll.
	<i>Lepidium densiflorum</i> Schrad.	common pepperweed	N	A	
	<i>Streptanthus cordatus</i> Nutt.	heartleaf twistflower	N	P	Trail up Mt. Trumbull
Capparaceae	<i>Cleome lutea</i> Hook.	yellow spiderflower	N	A	
	<i>Cleome serrulata</i> Pursh	Rocky Mtn. bee plant	N	A	
Caprifoliaceae	<i>Sambucus nigra</i> ssp. <i>cerulea</i> (Raf.) R. Bolli	elderberry	N	T	<i>Sambucus cerulea</i>
	<i>Symphoricarpos oreophilus</i> Gray	whortleleaf snowberry	N	S	
Caryophyllaceae	<i>Arenaria eastwoodiae</i> Rydb.	Eastwood's sandwort	N	P	
	<i>Arenaria fendleri</i>	Fendler's sandwort	N	P	Crest of Mt. Logan, check author
	<i>Arenaria lanuginosa</i> ssp. <i>saxosa</i> (Gray) Maquire	spreading sandwort	N	P	
	<i>Pseudostellaria jamesiana</i> (Torr.) W. A. Weber & R.L. Hartman	tuber starwort	N	P	<i>Stellaria jamesiana</i> - EB4 in wash

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	<i>Silene scouleri</i> Hook.	Scouler's campion	N	P	NE aspect - Mt. Logan
Chenopodiaceae	<i>Chenopodium berlandieri</i> var. <i>berlandieri</i> Moq.	Berlandier's goosefoot	N	A	<i>Chenopodium album</i> var. <i>berlandieri</i>
	<i>Chenopodium botrys</i> L.	Jerusalem oak goosefoot	I	A	2 spec. in 96-1 after burn, common in seed bank
	<i>Chenopodium graveolens</i> Willd.	fetid goosefoot	N	A	
	<i>Chenopodium leptophyllum</i> (Moq.) Nutt. ex S. Wats.	narrowleaf goosefoot	N	A	
Convolvulaceae	<i>Convolvulus arvensis</i> L.	field bindweed	I	P	
Cupressaceae	<i>Juniperus osteosperma</i> (Torr.) Little	Utah juniper	N	T	
Cyperaceae	<i>Carex occidentalis</i> Bailey	western sedge	N	P	
Ericaceae	<i>Arctostaphylos patula</i> Greene	greenleaf manzanita	N	S	Cottam - called it <i>A. platyphylla</i>
	<i>Arctostaphylos pungens</i> Kunth	pointleaf manzanita	N	S	
Euphorbiaceae	<i>Chamaesyce serpyllifolia</i> var. <i>serpyllifolia</i> (Pers.) Small	thymeleaf sandmat	N	A	<i>Euphorbia serpyllifolia</i>
	<i>Euphorbia brachycera</i> Engelm.	horned spurge	N	P	
	<i>Euphorbia lurida</i> Engelm.	San Francisco Mtn. spurge	N	P	
Fabaceae	<i>Astragalus argophyllus</i> Nutt.	silverleaf milkvetch	N	P	
	<i>Astragalus argophyllus</i> var. <i>stocksii</i> Barneby ex Isely	silverleaf milkvetch	N	P	
	<i>Astragalus castaneiformis</i> S. Wats.	chestnut milkvetch	N	P	Cottam - Mt. Emma
	<i>Astragalus oophorus</i> var. <i>caulescens</i> (M.E. Jones)	egg milkvetch	N	P	
	<i>Dalea candida</i> var. <i>oligophylla</i> (Torr.) Shinners	white prairieclover	N	P	
	<i>Dalea polygonoides</i> Gray	sixweeks prairieclover	N	P	Cottam, but not collected by NAU
	<i>Dalea searsiae</i> (Gray) Barneby	Searls' prairieclover	N	P	
	<i>Lathyrus laetivirens</i> Greene ex Rydb.	aspen peavine	N	P	
	<i>Lotus humistratus</i> Greene	foothill deervetch	N	A	Check McKee for occurrence, not coll. by NAU
	<i>Lotus utahensis</i> Ottley	Utah birdsfoot trefoil	N	P	
	<i>Lotus wrightii</i> (Gray) Greene	Wright's deervetch	N	P	
	<i>Lupinus argenteus</i> Pursh	silvery lupine	N	P	
	<i>Lupinus formosus</i> var. <i>robustus</i> C.P. Sm.	summer lupine	N	P	Cottam - <i>L. greenei</i> , not in AZ per PLANTS
	<i>Lupinus kingii</i> S. Wats.	King's lupine	N	A	
	<i>Medicago sativa</i> L.	alfalfa	I	P	
	<i>Melilotus officinalis</i> (L.) Lem.	yellow sweet-clover	I	P	
	<i>Phaseolus angustissimus</i> Gray	slimleaf bean	N	P	Logan Burn
	<i>Psoraleidium tenuiflorum</i> (Pursh.) Rydb.	slimflower scurfpea	N	P	
	<i>Robinia neomexicana</i> Gray	New Mexico locust	N	P	
	<i>Vicia americana</i> Muhl. ex Willd.	American vetch	N	P	
Fagaceae	<i>Quercus gambelii</i> Nutt.	Gambel's oak	N	T	

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	<i>Quercus gambelii</i> Nutt. x <i>Quercus turbinella</i> Greene	hybrid	N	S	
	<i>Quercus turbinella</i> Greene	shrub live oak	N	S	
Fumariaceae	<i>Corydalis aurea</i> Willd.	scrambled eggs	N	A	disturbed areas, fires, 96-1
Garryaceae	<i>Garrya flavescens</i> S. Wats.	ashy silktassel	N	P	
Gentianaceae	<i>Frasera albomarginata</i> var. <i>albomarginata</i> S. Wats.	desert elkweed	N	P	<i>Swertia albomarginata</i> , along C.R. 5
	<i>Frasera speciosa</i> Dougl. ex Griseb.	showy fraseria	N	P	<i>Swertia radiata</i>
Geraniaceae	<i>Erodium cicutarium</i> (L.) L'Her. ex Ait.	redstem stork's bill	I	A	
	<i>Geranium caespitosum</i> James	pineywoods geranium	N	P	
	<i>Geranium richardsonii</i> Fisch. & Trautv.	Richardson's geranium	N	P	
Grossulariaceae	<i>Ribes cereum</i> Dougl.	wax currant	N	S	
	<i>Ribes</i> sp. L.	currant	N	S	Slide Mtn. - has spines - spec. missing
Hydrophyllaceae	<i>Nama dichotomum</i> (Ruiz & Pavon) Choisy	wishbone fiddleleaf	N	A	Looks very similar to <i>Phlox gracilis</i>
	<i>Phacelia crenulata</i> var. <i>corrugata</i> (A. Nels.) Brand	cleftleaf wild heliotrope	N	P	Cottam
	<i>Phacelia egea</i> (Greene ex Brand) Greene ex J.T. Howell	Kaweah River scorpionweed	N	P	<i>P. magellanica</i>
	<i>Phacelia</i> sp.		N	P	Lava Burn, only one, not coll., not flwmg.
Lamiaceae	<i>Dracocephalum parviflorum</i> Nutt.	American dragonhead	N	A/B	<i>Moldavica parviflora</i>
	<i>Leonurus cardiaca</i> (L.)	common motherwort	I	P	common under oaks
	<i>Marrubium vulgare</i> L.	horehound	I	P	
	<i>Monardella odoratissima</i> Benth.	Pacific monardella	N	P	Lava flows
	<i>Nepeta cataria</i> L.	catnip	I	P	Based on leaf shape, no flowers observed
Liliaceae	<i>Allium bisceptrum</i> var. <i>palmeri</i> (S. Wats.) Cronq.	aspen onion	N	P	
	<i>Calochortus nuttallii</i> Torr. & Gray	sego lily	N	P	
	<i>Fritillaria atropurpurea</i> Nutt.	spotted missionbells	N	P	
Linaceae	<i>Linum australe</i> Heller	southern flax	N	A	Keyed using IMF. <i>L. aristatum</i> w/Macdoug.
	<i>Linum lewisii</i> Pursh	prairie flax	N	P	
Loasaceae	<i>Mentzelia dispersa</i> S. Wats.	bushy blazingstar	N	A	May be first occurrence in AZ
	<i>Mentzelia pumila</i> Nutt. ex Torr. & Gray	dwarf mentzelia	N	P	
Malvaceae	<i>Spharalcea parvifolia</i> A. Nels.	smallflower globemallow	N	P	
Monotropaceae	<i>Pterospora andromedea</i> Nutt.	woodland pinedrops	N	P	
Nyctaginaceae	<i>Mirabilis decipiens</i> (Standl.) Standl.	broadleaf four o'clock	N	P	
	<i>Mirabilis linearis</i> (Pursh) Heimerl	narrowleaf four o'clock	N	P	
	<i>Mirabilis oxybaphoides</i> (Gray) Gray	smooth spreading four o'clock	N	P	
	<i>Mirabilis pumila</i> ? (Standl.) Standl.	dwarf four o'clock	N	P	
Onagraceae	<i>Epilobium angustifolium</i> ssp. <i>angustifolium</i> L.	fireweed	N	P	Lava flow - EB1

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	<i>Gayophytum diffusum</i> Torr. & Gray	spreading groundsmoke	N	A	
	<i>Oenothera caespitosa</i> Nutt.	tufted eveningprimrose	N	P	
	<i>Oenothera coronopifolia</i> Torr. & Gray	crownleaf eveningprimrose	N	P	Roadside - CR 5
	<i>Oenothera flava</i> (A. Nels.)	yellow eveningprimrose	N	P	Sawmill Tank
Orobanchaceae	<i>Orobanche fasciculata</i> Nutt	clustered broomrape	N	P	parasitic on ARTR, check current listing status
Papaveraceae	<i>Argemone munita</i> Dur. & Hilg.	flatbud pricklypoppy	N	P	
	<i>Eschscholzia californica</i> ssp. <i>mexicana</i> (Greene) C. Clark	California poppy	N	A	Cottam
Pinaceae	<i>Pinus edulis</i> Engelm.	twoneedle pine	N	T	
	<i>Pinus ponderosa</i> P. & C. Lawson	ponderosa pine	N	T	
Poaceae	<i>Achnatherum hymenoides</i> (Roemer & J.A. Schultes) Barkworth	Indian ricegrass	N	P	<i>Oryzopsis hymenoides</i>
	<i>Agropyron cristatum</i> (L.) Gaertn.	crested wheatgrass	I	P	
	<i>Aristida purpurea</i> var. <i>longiseta</i> (Steud.) Vasey	Fendler threeawn	N	P	
	<i>Bouteloua curtipendula</i> (Michx.) Torr.	sideoats grama	N	P	
	<i>Bouteloua gracilis</i> (Willd. ex Kunth) Lag. ex Griffiths	blue grama	N	P	
	<i>Bromus ciliatus</i> L.	fringed brome	N	P	
	<i>Bromus inermis</i> Leyss.	smooth brome	I	P	
	<i>Bromus marginatus</i> Nees ex Steud.	mountain brome	N	P	Cottam - Mt. Emma
	<i>Bromus tectorum</i> L.	cheatgrass	I	A	
	<i>Elymus elymoides</i> ssp. <i>elymoides</i> (Raf.) Swezey	wildrye	N	P	<i>Sitanion hystrix</i>
	<i>Elymus trachycaulus</i> ssp. <i>trachycaulus</i> (Link) Gould ex Shinnars	slender wheatgrass	N	P	
	<i>Elytrigia elongata</i> (Host) Nevski	tall wheatgrass	I	P	<i>Agropyron elongatum</i>
	<i>Elytrigia intermedia</i> (Host) Nevski	intermediate wheatgrass	I	P	<i>A. intermedium</i> var. <i>trichophorum</i>
	<i>Elytrigia intermedia</i> ssp. <i>intermedia</i> (Host) Nevski	intermediate wheatgrass	I	P	<i>A. intermedium</i> var. <i>intermedium</i>
	<i>Eragrostis mexicana</i> (Hornem.) Link	Mexican lovegrass	N	A	Cottam - not collected by NAU
	<i>Festuca arizonica</i> Vasey	Arizona fescue	N	P	Only in Logan burn
	<i>Hesperostipa comata</i> ssp. <i>comata</i> (Trin. & Rupr.) Barkworth	ncn	N	P	<i>Stipa comata</i>
	<i>Koeleria macrantha</i> (Ledeb.) J.A. Schultes	prairie junegrass	N	P	<i>K. nitida</i> , <i>K. cristata</i>
	<i>Leymus cinereus</i> (Scribn. & Men.) A. Love	basin wildrye	N	P	
	<i>Monroa squarrosa</i> (Nutt.) Torr.	false buffalograss	N	A	Logan burn
	<i>Muhlenbergia minutissima</i> (Steud.) Swallen	annual muhly	N	A	
	<i>Muhlenbergia repens</i> (J. Presl.) A. S. Hitchc.	creeping muhly	N	P	
	<i>Muhlenbergia wrightii</i> Vasey ex Coult.	spike muhly	N	P	
	<i>Piptatherum micranthum</i> (Trin. & Rupr.) Barkworth	smillograss	N	P	<i>Oryzopsis micrantha</i>
	<i>Poa fendleriana</i> (Steud.) Vasey	muttongrass	N	P	

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	<i>Poa pratensis</i> L.	Kentucky bluegrass	I	P	
	<i>Schizachyrium scoparium</i> (Michx.) Nash	little bluestem	N	P	
	<i>Secale cereale</i> L.	cultivated rye	I	A	
	<i>Sporobolus cryptandrus</i> (Torr.) Gray	sand dropseed	N	P	
Polemoniaceae	<i>Gillia sinuata</i> Dougl. Ex Benth.	rosy gillia	N	A	Cottam
	<i>Ipomopsis aggregata</i> (Pursh) V. Grant	skyrocket gillia	N	P	
	<i>Ipomopsis arizonica</i> (Greene) Wherry	Arizona skyrocket	N	P	
	<i>Ipomopsis multiflora</i> (Nutt.) V. Grant	manyflowered gillia	N	P	
	<i>Navarretia breweri</i> (Gray) Greene	Brewer's navarretia	N	A	Near Mt. Trumbull 5900' - N. Brian list
	<i>Phlox austromontana</i> Coville	desert phlox	N	P	Nixon Springs pipeline
	<i>Phlox gracilis</i> (Hook.) Greene	slender phlox	N	A	
	<i>Phlox longifolia</i> Nutt.	longleaf phlox	N	P	
Polygonaceae	<i>Eriogonum alatum</i> Torr.	winged buckwheat	N	P	C.R. 5
	<i>Eriogonum corymbosum</i> var. <i>corymbosum</i> Benth.	crispleaf buckwheat	N	P?	
	<i>Eriogonum cernuum</i> Nutt.	nodding buckwheat	N	A	
	<i>Eriogonum pharnaceoides</i> var. <i>cervinum</i> Reveal	wirestem buckwheat	N	A	
	<i>Eriogonum racemosum</i> Nutt.	redroot buckwheat	N	P	
	<i>Eriogonum trichopes</i> Torr.	little deserttrumpet	N	A	Cottam
	<i>Eriogonum umbellatum</i> Torr.	sulphur wildbuckwheat	N	P	
	<i>Eriogonum</i> sp. Michx.	buckwheat	N	A	Slide Mtn. - missing specimens
	<i>Polygonum convolvulus</i> L.	black bindweed	I	A	
	<i>Polygonum douglasii</i> ssp. <i>johnstonii</i> (Munz) Hickman	Johnston's knotweed	N?	A	<i>P. sawatchense</i>
Polypodiaceae	<i>Cheilanthes feei</i> T. Moore	slender lipfern	N	P	Cottam
	<i>Cystopteris fragilis</i> (L.) Bernh.	brittle bladderfern	N	P	
	<i>Woodsia scopulina</i> D. C. Eat.	Rocky Mountain woodsia	N	P	Cottam
Portulacaceae	<i>Portulaca oleracea</i> L.	little hogweed	N?	A	May be introduced
Ranunculaceae	<i>Ceratocephala testiculata</i> (Crantz) Bess.	curvseed butterwort	I	A	<i>Ranunculus testiculatus</i>
	<i>Clematis ligusticifolia</i> Nutt.	western white clematis	N	P	EB4
	<i>Delphinium nuttallianum</i> var. <i>nuttallianum</i> Pritz. ex Walp.	Nuttal's larkspur	N	P?	
	<i>Ranunculus oreogenes</i> Greene	Oregon buttercup	N	P	
	<i>Thalictrum fendleri</i> Engelm. ex Gray	Fendler's meadowrue	N	P	
Rhamnaceae	<i>Ceanothus fendleri</i> Gray	Fendler's ceanothus	N	S	
	<i>Ceanothus martinii</i> M.E. Jones	Martin's ceanothus	N	S	
Rosaceae	<i>Amelanchier alnifolia</i> (Nutt.) ex M. Roemer	Saskatoon serviceberry	N	S/T	

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	<i>Amelanchier utahensis</i> Koehne	Utah serviceberry	N	S/T	
	<i>Antennaria</i> sp. Gaertn.	pussytoes	N	P	
	<i>Cercocarpus ledifolius</i> var. <i>intermontanus</i> N. Holmgren	curleaf mountain mahogany	N	S/T	Mt. Logan - Hell's Hole Overlook
	<i>Fallugia paradoxa</i> (D. Don) Endl. ex Torr.	Apacheplume	N	S	
	<i>Petrophyton caespitosum</i> (Nutt.) Rydb.	mat rockspirea	N	P	Cottam
	<i>Prunus emarginata</i> (Dougl. ex Hook.) Walp.	bitter cherry	N	S/T	
	<i>Purshia stansburiana</i> (Torr.) Henrickson	Stansbury cliffrose	N	S	
	<i>Purshia tridentata</i> (Pursh) DC.	antelope bitterbrush	N	S	
	<i>Rosa woodsii</i> var. <i>ultramontana</i> (S. Wats.) Jepson	Woods' rose	N	S	
Rubiaceae	<i>Galium bifolium</i> S. Wats.	twingleaf bedstraw	N	A	Check current listing status
	<i>Galium</i> sp. L.	bedstraw	N	P	Slide Mtn. - missing specimens
	<i>Galium wrightii</i> Gray	Wright's bedstraw	N	P	
	<i>Kelloggia galioides</i> Torr.	milk kelloggia	N	P	
Rutaceae	<i>Ptelia trifoliata</i> ssp. <i>pallida</i> (Greene) V. Bailey	common hoptree	N	S/T	
Salicaceae	<i>Populus tremuloides</i> Michx.	quaking aspen	N	T	
Santalaceae	<i>Comandra umbellata</i> ssp. <i>pallida</i> (A. DC.) Piehl	pale bastard toadflax	N	P	
Saxifragaceae	<i>Heuchera parvifolia</i> Nutt. Ex Torr. & Gray	littleleaf alumroot	N	P	Cottam - Mt. Emma
	<i>Heuchera rubescens</i> Torr.	pink alumroot	N	P	Check current listing status
Scrophulariaceae	<i>Castilleja integra</i> Gray	wholeleaf Indian paintbrush	N	P	
	<i>Castilleja linariifolia</i> Benth.	Wyoming Indian paintbrush	N	P	
	<i>Collinsia parviflora</i> Lindl.	smallflower blue-eyed Mary	N	A	
	<i>Cordylanthus parviflorus</i> (Ferris) Wiggins	purple bird's beak	N	A	
	<i>Mimulus bigelovii</i> var. <i>bigelovii</i> (Gray) Gray	Bigelow's monkeyflower	N	A	One spec. in 96-1 after burn, not collected
	<i>Mimulus rubellus</i> Gray	red monkeyflower	N	A	
	<i>Pedicularis centranthera</i> Gray	dwarf lousewort	N	P	
	<i>Penstemon barbatus</i> (Cav.) Roth	beardlip penstemon	N	P	
	<i>Penstemon eatonii</i> Gray	Eaton's penstemon	N	P	N.S. pipeline - side of Mt. Trumbull
	<i>Penstemon linarioides</i> ssp. <i>sileri</i> (Gray) Keck	Siler's penstemon	N	P	
	<i>Penstemon linarioides</i> ssp. unknown	mat penstemon	N	P	5 ssp. in AZ - don't have good key yet
	<i>Penstemon ophianthus</i> Pennell	coiled anther penstemon	N	P	Cottam - juniper slopes
	<i>Penstemon pachyphyllus</i> Gray ex Rydb.	thick-leaf beardtongue	N	P	Also have pink phase - expert ID?
	<i>Penstemon pachyphyllus</i> var. <i>congestus</i> (M.E.Jones) N. Holmgren	thickleaf beardtongue	N	P	Cottam
	<i>Penstemon palmeri</i> Gray	Palmer's penstemon	N	P	
	<i>Penstemon rostriflorus</i> Kellogg	Bridge penstemon	N	P	P. bridgesii

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	<i>Penstemon thompsoniae</i> (Gray) Rydb.	Thompson's beardtongue	N	P	uncommon at MT - not collected
	<i>Verbascum thapsus</i> L.	common mullein	I	B	
Solanaceae	<i>Datura wrightii</i> Regel	sacred thornapple	N	P	Logan burn
	<i>Nicotiana attenuata</i> Torr. Ex S. Wats.	coyote tobacco	N	A	
	<i>Physalis hederifolia</i> Gray	ivyleaf ground cherry	N	P	
	<i>Physalis hederifolia</i> var. <i>palmeri</i> (Gray) Cronq.	Palmer's groundcherry	N	P	Not in AZ per PLANTS database
	<i>Solanum jamesii</i> Torr.	wild potato	N	P	
	<i>Solanum triflorum</i> Nutt.	cutleaf nightshade	N	A	
Verbenaceae	<i>Glandularia gooddingii</i> (Briq.) Solbrig	southwestern mock vervain	N	P	Verbena gooddingii
	<i>Verbena bracteata</i> Laq. & Rodr.	bigbract verbena	N	P	Only in seedbank? Check datasheets
Violaceae	<i>Viola canadensis</i> L.	Canadian white violet	N	P	
	<i>Viola nuttallii</i> Pursh	Nuttall's violet	N	P	No AZ specimens in Deaver Herbarium
Viscaceae	<i>Phoradendron juniperinum</i> Engelm.	juniper mistletoe	N	P	

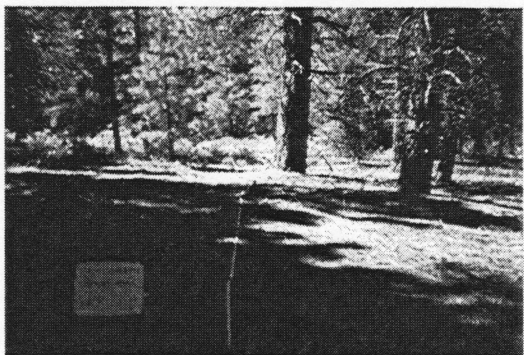
APPENDIX B. EXPERIMENTAL BLOCK PHOTOS



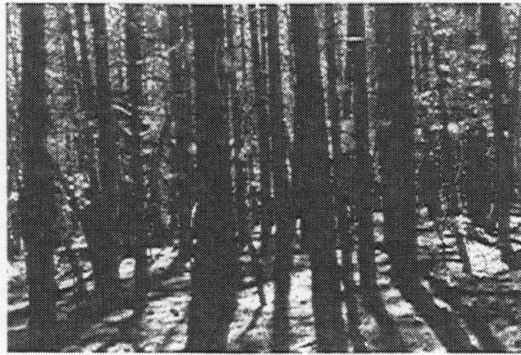
Appendix B. Figure 1. Block 1



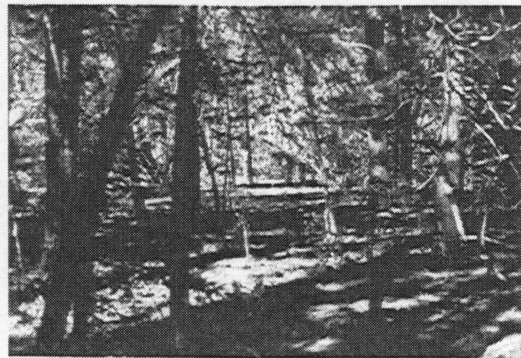
Appendix B. Figure 2. Block 2.



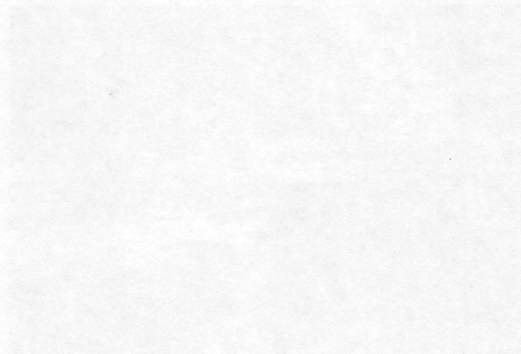
Appendix B. Figure 3. Block 3



Appendix B. Figure 4. Block 4



Appendix B. Figure 5. Block 5



APPENDIX C. METRIC TO ENGLISH CONVERSION

Multiply:	By:	To get:
Number/ha	0.4047	Number/acre
M ² /ha	4.3554	Ft ² /acre
Ha	2.4710	Acres
Cm	2.54	Inches
M	3.2808	Ft
Km	0.6214	Miles
Metric ton/ha	0.4461	English ton/acre